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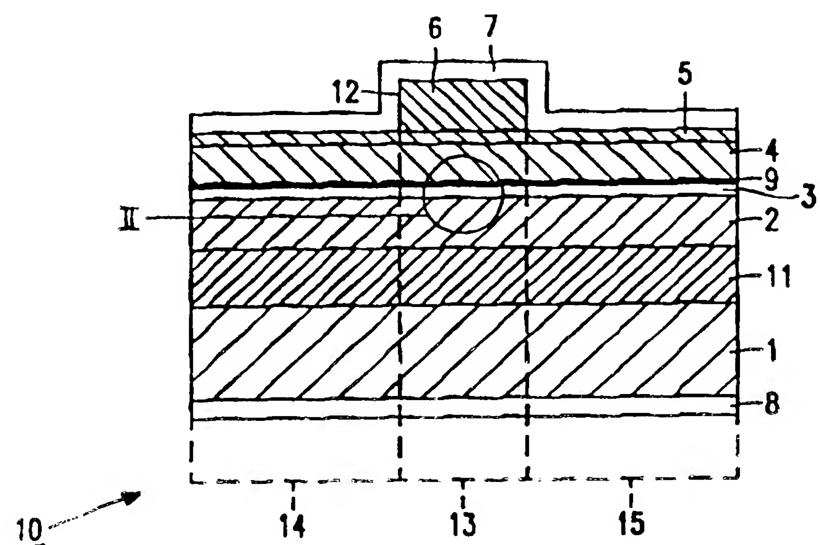
(54) Title: RADIATION-EMITTING SEMICONDUCTOR DIODE, AND METHOD OF MANUFACTURING SUCH A DIODE

(57) Abstract



A radiation-emitting semiconductor diode with a substrate (1) on which are situated: a first cladding layer (2), an active layer (3), and a second cladding layer (4), forms an important component in information-processing systems such as optical disc systems, especially when constructed as a laser. A laser in the GaInP/AlGaInP material system has a desired short-wave emission of, for example, 630 nm. According to the invention, such a diode comprises a barrier layer (9) which is present between the second cladding layer (4) and the active layer (3) and which prevents dopant elements, for example zinc atoms, from moving from the second cladding layer (4) to the active layer (3). The degradation which would otherwise occur was found to be connected with a local displacement of the pn junction from the second cladding layer owing to the stress in the layer structure which is necessary for the photoelastic effect. The barrier layer (9) preferably comprises two or more sub-layers (9A, 9B) with alternately a high and a low bandgap, in the GaInP/AlGaInP material system made of AlGaInP or AlInP with alternately a high and a low aluminum content. Such a barrier layer at the same time increases the efficiency of the diode according to the invention. In a major embodiment, the doping profile has a stepped gradient on either side of the active layer (3).

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Radiation-emitting semiconductor diode, and method of manufacturing such a diode.

The invention relates to a radiation-emitting semiconductor diode, in particular to a semiconductor diode laser often called laser hereinafter for short, comprising a semiconductor body with a semiconductor substrate on which are present at least in that order a first cladding layer of a first conductivity type, an active layer, and a second cladding layer of a second conductivity type opposed to the first, the first and second cladding layers being provided with means for the supply of an electric current and with a pn junction which, given a sufficiently high current strength in the forward direction, is capable of generating electromagnetic radiation in a strip-shaped active region of the active layer, while the surface of the semiconductor body is provided with at least one covering layer which is under mechanical stress and the surface of the semiconductor body or the covering layer is geometrically structured such that, and the mechanical stress of the covering layer is chosen such that the effective refractive index for the generated radiation is reduced in the active layer on either side of the strip-shaped active region. The invention also relates to a method of manufacturing such a diode and to a method of operating the laser version of such a diode.

Such a radiation-emitting diode, especially when constructed as a laser and when the wavelength of the emission lies in the visible range of the spectrum, forms a particularly suitable radiation source for inter alia information processing systems such as laser printers with which information is written, and such as optical disc systems in which information is read, for example so-called Compact Disc (CD) and Video Long Play (VLP) players, or is written and read, for example Digital Optical Recording (DOR). There are numerous applications in optoelectronic systems as well when such diodes are constructed as LEDs.

Such a radiation-emitting diode and such a method of manufacturing it are known from the article by R. Maciejko et al., "Photoelastic Effects on the emission patterns of InGaAsP ridge waveguide lasers" published in IEEE Journal of Quantum Electronics, vol 25, no. 4, 4 April 1989, pp. 651-660. This describes a laser (see Fig. 2) in which an

InGaAsP active layer, a p-type InP second cladding layer, and an InGaAs(P) contact layer are present on an n-type InP substrate which also acts as the first cladding layer. The laser shown here is of the ridge waveguide type and of the index-guided type because the ridge comprises the entire second cladding layer. This means that the effective refractive index is lower on either side of the active region than in the active region. The surface of the laser is covered with a covering layer which has a mechanical stress, comprises an oxide, is provided with an opening above the ridge, and in its turn is covered with a metal layer. Fig. 7 of the article shows that an additional lowering of the effective refractive index occurs on either side of the active region in such a laser if the covering has a tension stress. Indeed, said tension stress in the covering layer introduces a compression stress on either side of the active region, and this in its turn leads to an additional lowering of the effective refractive index on either side of the active region as a result of a photoelastic effect. A narrow active region is promoted thereby, and as a result a more (circular-) symmetrical pattern of the emerging radiation beam. In addition, the starting current of the laser is comparatively low because of this, which is also very favorable.

It is a disadvantage of the known semiconductor diode when constructed as a laser that it shows a stronger degradation when used at a lower temperature, for example at 30 °C, than at a higher temperature, for example 50 to 80 °C. This is highly surprising because in general degradation tends to occur more readily at higher temperatures. Sometimes, however, the use at low temperature, for example in pulsed operation, is desirable, and in that case the degradation is inadmissibly high.

The present invention accordingly has for its object inter alia to realize a radiation-emitting semiconductor diode (and a simple method of manufacturing it) which do not involve the above disadvantage, or at least to a much lesser degree, the laser version of the diode showing a low degradation also at a low operating temperature.

According to the invention, a radiation-emitting semiconductor diode of the kind described in the opening paragraph is for this purpose characterized in that a barrier layer preventing the diffusion of dopant elements of the second conductivity type from the second cladding layer into the active layer is present between the active layer and the second cladding layer. The invention is based in the first instance on the surprising experimental result that the degradation which occurs especially in the use of a laser version of a diode at low temperature is connected with a displacement of the pn junction. This displacement is

found to occur mainly locally, i.e. approximately below the lateral sides of the ridge, and comprises a shift in the direction of and up to inside the first cladding layer. The invention is further based on the recognition that this local displacement is also partly caused by the stress in the structure present in situ. This stress promotes a local migration of atoms which give the second cladding layer the second conductivity type, for example zinc atoms, from the second cladding layer through the active layer to and into the first cladding layer. A pn junction which has been displaced (too far) results in degradation. The invention is finally based on the recognition that said displacement of the pn junction can be counteracted in that a barrier layer is provided between the second cladding layer and the active layer, i.e. a barrier obstructing the passage of dopant elements of the second conductivity type. The diode according to the invention, when constructed as a laser, has a particularly low degradation also at a low operating temperature: it is characterized by a total increase in the starting current of, for example, 5 %, whereas the known diode in that case shows an increase in the starting current of 100 %. It is noted that the expression "barrier layer between the active layer and the second cladding layer" is also understood to cover a barrier layer which is present within the active layer but in the portion thereof adjoining the second cladding layer as well as a barrier layer which is present within the second cladding layer at a small distance from the active layer, for example, separated therefrom by a so-called separate confinement layer. The barrier layer is thus effective at least for the major portion of the active layer or the major portion of the second cladding layer.

In a preferred embodiment of a radiation-emitting semiconductor diode according to the invention, the barrier layer comprises two or more sub-layers which have alternately a high and a low bandgap value. Such a barrier layer is found to be very effective in practice. A possible mechanism is that such a barrier layer prevents charge carriers, electrons in this case, from penetrating from the active layer into the cladding layer and giving off energy there which would promote a displacement of, for example, zinc atoms. If the barrier layer or the sub-layers is/are thin, for example thinner than 10 nm, they are allowed to have a mechanical stress without defects being caused thereby which would promote the degradation. Both a tension and a compression stress promote the effectivity of the barrier layer against, for example, zinc atoms: in the former case the lattice constant of the barrier layer is small(er), so that the zinc atoms, which are also small, are energetically stopped. In the latter case, the lattice constant of the barrier layer is great, so that it is indeed energetically favorable for the small zinc atoms to penetrate the barrier layer, but they are subsequently retained therein. The use of either kind of stress has the additional advantage

that the total net stress in the barrier layer can be very small as a result of compensation. The risk of defects arising is absent or at least very small as a result.

In a very favorable embodiment, the doping concentration at at least one side of the active layer, but preferably at both sides thereof, has a gradient, preferably stepwise, from a low to a high doping concentration. A low doping concentration (instead of, for example, a doping concentration equal to zero) has a stabilizing effect on the location of the pn junction. Such a concentration also reduces the diffusion length of the charge carriers, so that the latter can penetrate less far into the cladding layer and promote the diffusion of, for example, zinc there. A high doping concentration close to the active layer is undesirable because of its unfavorable influence on the luminescence, whereas a high doping concentration (farther away) in the cladding layer does not have this influence and is very favorable for the series resistance of the diode.

In a major embodiment, the surface of the semiconductor body is geometrically structured in that the semiconductor body is provided with a strip-shaped mesa which comprises at most a portion of the second cladding layer and which is present above the strip-shaped active region, while the covering layer comprises a metal layer which extends over the mesa and on either side thereof and is under a compression stress. The metal layer forms a current-blocking junction with the subjacent portion of the second cladding layer or with an intermediate layer, if present, on either side of the mesa. A covering layer comprising an oxide as known from the prior art diode may be absent in this embodiment, and no photolithographic process need be used for contacting of the diode. The manufacture of a diode according to the invention is very simple as a result of this.

In a particularly attractive modification of this embodiment, the strip-shaped mesa comprises exclusively a contact layer of the second conductivity type which is present on the second cladding layer, and the thickness and composition of the second cladding layer are chosen such that the generated radiation is fully confined at the side of the second cladding layer. Owing to this construction, the diode is in principle of the gain-guided type, which means that the current distribution determines the profile of the radiation beam. A purely gain-guided laser is often not of great practical use because a so-called anti-guiding effect may readily arise owing to various causes, whereby a filamentation of the radiation beam occurs. The compression stress in the covering layer, however, renders the present modification of the diode weakly index-guided, which ensures a symmetrical and non-filamented radiation beam. It is noted that surprisingly the covering layer must have a compression stress in these cases so as to obtain the desired (additional) reduction in the

effective refractive index on either side of the ridge, and not a tension stress as in the known structure.

Preferably, the diode according to the invention is constructed as a laser, the substrate comprises n-type GaAs, the respective n-type and p-type cladding layers comprise AlGaInP or AlInP, the active layer comprises GaInP or AlGaInP with a lower aluminum content than the cladding layers, the diode comprises a contact layer of p-type GaAs, the second cladding layer is doped with zinc atoms, the barrier layer comprises two or more layers of AlGaInP or AlInP with alternately a high and a low aluminum content, and the covering layer which is under mechanical stress comprises a tantalum layer.

A method of manufacturing a radiation-emitting diode whereby a semiconductor body is formed through the provision on a semiconductor substrate of, in that order: at least a first cladding layer of the first conductivity type, an active layer, and a second cladding layer of a second conductivity type, the surface of the semiconductor body being provided with a covering layer which is under mechanical stress, and the surface of the semiconductor layer or the covering layer being geometrically structured such that, and the mechanical stress of the covering layer being chosen such that the effective refractive index for the radiation to be generated is reduced in the active layer on either side of a strip-shaped active region forming part of the active layer, is characterized according to the invention in that a barrier layer is provided between the active layer and the second cladding layer, which barrier layer prevents dopant atoms of the second conductivity type from moving from the second cladding layer into the active layer. A diode according to the invention is obtained in a simple manner by such a method.

Preferably, in a method according to the invention, zinc is chosen as the dopant of the second conductivity type, the barrier layer is formed by two or more sub-layers with alternately a high and a low bandgap, the doping levels of the cladding layers on either side of the active layer are provided stepwise from low to high, and a layer comprising tantalum is chosen for the covering layer, the latter being provided by diode sputtering at a high power or at a low argon pressure.

The invention will now be explained in more detail with reference to an embodiment and the accompanying drawing, in which

Fig. 1 is a diagrammatic cross-section of an embodiment of a radiation emitting semiconductor diode according to the invention;

Fig. 2 is a diagrammatic cross-section taken on the line II in Fig. 1 of a detail of the diode of Fig. 1; and

Figs. 3 and 4 diagrammatically and in cross-section show the diode of Fig. 1 in consecutive stages of its manufacture by a method according to the invention.

The Figures are diagrammatic and not drawn true to scale, the dimensions in the thickness direction being particularly exaggerated for greater clarity. Corresponding parts have generally been given the same reference numerals in the various examples. Semiconductor regions of the same conductivity type have generally been hatched in the same direction.

The cross-section of Fig. 1 shows a radiation-emitting semiconductor diode according to the invention constructed as a laser. Fig. 2 shows a detail II of the laser of Fig. 1. The laser comprises a semiconductor body 10 with a substrate region 1 of a first conductivity type, here the n-type, provided with a connection conductor 8 and comprising monocrystalline gallium arsenide in this example. A semiconductor layer structure is provided on this, comprising inter alia a buffer layer 11 of the same, i.e. the n-conductivity type. Silicon atoms are used for the n-type doping in this example. On the above assembly the following are provided in that order: a first cladding layer 2 of the n-conductivity type, an active layer 3, a second cladding layer 4 of the opposed, i.e. p-conductivity type, and a contact layer 6 also of the p-type. Zinc atoms are used for the p-type doping here. The surface of the semiconductor body 10 is geometrically structured in that it is provided with a strip-shaped mesa 12 which here comprises exclusively the contact layer 6, the doping profile of which is provided in steps. A pn junction present between the cladding layers 2 and 4 is capable of generating electromagnetic radiation in a strip-shaped active region 13 present in the active layer 3 below the mesa 12, given a sufficient current strength in the forward direction. A covering layer 7 extends over the surface of the semiconductor body, has a mechanical stress, a compression stress in this case, and comprises a metal layer 7 in this example which at the same time serves as an electrical connection for the second cladding layer 4. This geometric structure of the surface of the semiconductor body 10 and the covering layer 7, and the compression stress present therein give rise to a tension stress in the active layer 3 (approximately) below the edges of the mesa 12, which results in a lower effective refractive index in said locations for the generated radiation. This embodiment of the laser is weakly index-guided instead of purely gain-guided as a result. This means that

the radiation beam is forced underneath the mesa 12 and does not easily become filamented, but is rather more circular-symmetrical. The starting current of such a laser is also considerably lower than if the laser were of the gain-guided type, because in the latter case a so-called anti-guiding will arise in practice which leads to filamentation of the radiation beam and to an increase in the starting current of the laser.

According to the invention (see especially Fig. 2), a barrier layer 9 is present in the diode, so here in the laser, between the active layer 3 and the second cladding layer 4, which constitutes a barrier to dopant elements of the second conductivity type, so zinc atoms in this case, preventing at least that these doping elements move beyond the barrier layer into the active layer 3. The invention is based on a number of surprising finds and recognitions that a diode constructed as a laser shows a strong degradation especially at a low temperature of use; that this degradation is accompanied by, and indeed caused by a displacement of the pn junction; that this displacement is mainly local, i.e. approximately below the lateral edges of the mesa 12 and comprises a shift in the direction of and into the first cladding layer 2; that this local displacement is caused by the stresses present in the structure in situ, which stresses apparently promote migration of atoms which give the second cladding layer the second conductivity type, zinc atoms in this case, from the second cladding layer 4 through the active layer 3 to and into the first cladding layer 2; and finally that said displacement is counteracted by the application of a barrier layer 9 between the second cladding layer 4 and the active layer 3, thus raising a barrier to zinc atoms in this case which at least limits, or even prevents the displacement of said atoms altogether. The laser in this example shows a particularly low degradation also at a low operating temperature, for example in the case of pulsed operation: it is characterized by a total increase in the starting current of, for example, 3 %, whereas a laser comparable to the known diode shows a degradation of 100 % in that case. A diode according to the invention also has a very favorable degradation of, for example, 5 % at a higher temperature of use.

An important advantage of a diode according to the invention is that the barrier layer 9 not only constitutes a barrier to doping elements but is also capable of contributing to the efficiency. As a result, the laser in the present example has a particularly low starting current of, for example, 20 mA and a particularly low temperature-dependence of the starting current The starting current is 75 % higher in a laser whose covering layer 7 has no mechanical stress or the wrong mechanical stress, i.e. a tension stress in this case

In this example of a laser manufactured in the GaInP/AlGaInP material system, the barrier layer 9 is formed by two or more, in this case 20 sub-layers 9A, 9B with

alternately a high (9A) and a low (9B) aluminum content and all approximately 1 nm thick. The barrier layer 9 is not intentionally doped here but will have the p-type conductivity owing to doping from the adjoining layers 4a, 4b. The barrier layer 9 in this example in addition increases the efficiency of the diode according to the invention. The barrier layer 9 may advantageously be given a mechanical stress, a compression as well as a tension stress will improve the operation of the barrier. A combination of the two kinds of stress has the additional advantage that the net stress in the barrier layer 9 can be low or even zero, so that the generation of defects and the accompanying degradation can be avoided. In the present example, the two cladding layers 2, 4 comprise so-called separate confinement layers 2b, 2c, 4b, 4c of small thickness. These are not shown in the drawing. The barrier layer 9 is accordingly situated here within the second cladding layer 4 at a small distance from the active layer 3, this distance corresponding to the sum of the thicknesses of the separate confinement layers 4b, 4c. The doping concentration of the two cladding layers 2, 4 has a stepped gradient in this example: the portions of the cladding layers 2, 4 adjoining the active layer 3 have no more than the background doping - seen from the active layer 3 - which is, for example, approximately 10^{16}, then a somewhat higher doping concentration of $1*10^{17}$ at/cm^3, and finally a highest doping concentration of $2*10^{18}$ at/cm^3. A shift of the pn junction is further counteracted thereby, while the diffusion length of the charge carriers is sufficiently but not excessively limited, and the diode still has a useful series resistance of, for example, 6 Ω.

The covering layer 7, which comprises a metal layer 7 here, forms a current-blocking junction with the subjacent portion of the semiconductor body 10, in this case with an intermediate layer 5, on either side (14, 15) of the mesa 12. The metal layer 7 comprises the following sub-layers: a first sub-layer of platinum which provides the electrical contact with the semiconductor body 10 and which is preferably between 20 and 100 nm thick, 50 nm in this example. Then a second sub-layer of tantalum which is preferably between 100 and 200 nm thick, 150 nm in this example. This second sub-layer comprising tantalum gives the metal layer 7 a compression stress in this example. Finally, the metal layer 7 comprises a third sub-layer of gold which is preferably between 50 and 200 nm thick, 50 nm thick in this case, and which enables, for example, soldering of the laser. The metal layer 7 is preferably provided by sputtering. During the necessary alloying process of the platinum portion of the metal layer 7 with the semiconductor body 10, the former is given a tension stress. If the metal layer 7 is to be given a compression stress, as is necessary in this example, the alloying process of the platinum must take place before the sub-layers

comprising tantalum and gold of the metal layer 7 are provided. The sub-layer comprising tantalum is then given a sufficiently high compression stress, so that the resulting metal layer 7 will have the compression stress desired here (also after an unstressed layer comprising gold has been provided). The sub-layer comprising tantalum may be given a compression stress in that it is provided by diode sputtering at a comparatively low argon pressure, for example below approximately 25 μbar, or in that it is sputtered at a high power (for example during diode sputtering), in which case the temperature of the semiconductor body 10 becomes comparatively high, for example much higher than 300 °C, while the layer comprising tantalum is being provided. It is noted that a so-called annealing step should be avoided as much as possible here because any built-in compression stress is reduced by such a step or may even be converted into a tension stress.

The radiation-emitting semiconductor diode is constructed as a diode laser in this example. This means that the emission is coherent given a sufficient current strength. The strip-shaped mesa 12 is bounded perpendicularly to the longitudinal direction by two mutually parallel mirror surfaces lying in the plane of drawing and coinciding with natural cleaving surfaces of the crystal from which the semiconductor body was formed for the purpose of the diode laser version. This results in a resonant cavity for the generated radiation within the strips-shaped region 13 in the active layer 3.

The compositions, intentional doping concentrations, and thicknesses used for the various semiconductor layers in this example have been listed (once more) in the Table below

No.	Material	Type	Doping concentr. (at/cm³)	Thickness (μm)	Bandgap (eV)
1	GaAs	N	$2x10^{18}$	100	1,4
11	$Al_{0.20}Ga_{0.80}As$	N	$2x10^{18}$	0,1	1,7
2a	$Al_{0.35}Ga_{0.15}In_{0.50}P$	N	$2x10^{18}$	0,8	2,3
2b	$Al_{0.20}Ga_{0.30}In_{0.50}P$	N	$1x10^{17}$	0,096	2,15
2c	$Al_{0.20}Ga_{0.30}In_{0.50}P$	-	-	0,004	2,15
3	$Ga_{0.38}In_{0.62}P$ (2x)	-	-	0,006	1,9
	$Al_{0.20}Ga_{0.30}In_{0.5}P$ (1x)	-	-	0,004	2,15
4c	$Al_{0.20}Ga_{0.30}In_{0.50}P$	-	-	0,004	2,15
4b	$Al_{0.20}Ga_{0.30}In_{0.50}P$	P	$1x10^{17}$	0,096	2,15
9A	$Al_{0.35}Ga_{0.15}In_{0.50}P$ (10x)	-	-	0,002	2,3
9B	$Al_{0.20}Ga_{0.30}In_{0.50}P$ (10x)	-	-	0,002	2,15
4a	$Al_{0.35}Ga_{0.15}In_{0.50}P$	P	$4x10^{17}$	0,8	2,3
5	$Ga_{0.50}In_{0.50}P$	P	$1x10^{18}$	0,08	1,9
6	GaAs	P	$2x10^{18}$	0,25	1,4
	GaAs	P	$2x10^{19}$	0,2	1,4

The radiation emitted by this semiconductor diode has a wavelength of approximately 675 nm. The width of the mesa-shaped strip 12 is approximately 6 μm. The conductive layer 8 on the substrate 1 in this example is a gold-germanium-nickel layer with a thickness of approximately 100 nm.

The radiation-emitting semiconductor diode described is manufactured as follows according to the invention (see Figs. 3 and 4). Manufacture starts with a substrate 1 of monocrystalline n-type gallium arsenide with a doping concentration of $2x10^{18}$ at/cm³ and a thickness of, for example, 350 μm. After polishing and etching of the surface, which

preferably has a misorientation of at most 6 degrees relative to the (001) orientation, the following layers are grown on this surface, for example from the gas phase by means of OMVPE (- Organo Metallic Vapor Phase Epitaxy) in that order: the buffer layer 11, the first cladding layer 2, the active layer 3, the barrier layer 9 and the second cladding layer 4, the intermediate layer 5, and the contact layer 6. The materials, compositions, doping concentrations, and thicknesses for these layers are chosen as indicated in the Table above.

After the semiconductor layer structure thus obtained has been removed from the growing apparatus and has been cleaned in a usual manner, a strip-shaped mesa 12 is formed by etching through an SiO_2 mask 30 (see Fig. 4). The contact layer 6 is removed by means of an etchant comprising NH_3, H_2O_2, and H_2O in the ratio 2:1:50, the etching rate being approximately 0.7 μm/hour at room temperature. The intermediate layer 5 serves as an etching stopper layer. The mask 30 is subsequently removed, and the substrate 1 is grinded down to about 100 μm. Then the structure is introduced into a sputtering device upside down for providing the covering layer 7, i.e. a metal layer 7. First 50 nm Pt is provided. Then, in another sputtering process the metal layer 8 comprising AuGeNi is provided on the substrate 1. After removal from the sputtering device, the Pt is alloyed with the contact layer 6 of GaAs in an alloying oven at a temperature of 380 °C during 20 minutes in an argon atmosphere. After removal from the alloying oven and replacement in the sputtering device, the structure is given a 150 nm thick tantalum layer by means of diode sputtering at a power of 1000 watts and an argon pressure of $3x10^{-2}$ mbar. The tantalum layer is put under a compression stress of approximately 7 kbar thereby. Then a 50 nm thick gold layer is sputtered onto the tantalum layer, whereby the stress built up in the metal layer 7 is not changed anymore. After removal from the sputtering device, and after cleaving in two mutually perpendicular directions, the lasers obtained, having dimensions of, for example 300x300 μm^2, are ready for final mounting.

The invention is not limited to the embodiments given, since many modifications and variations are possible to those skilled in the art within the scope of the invention. Thus semiconductor materials or compositions of the chosen semiconductor materials other than those mentioned in the examples may be used, if so desired, such as those from the GaAs/AlGaAs or InP/InGaAsP material systems. Instead of weakly index-guided, the diode according to the invention may also be made strongly index guided, which means that a major portion of the second cladding layer forms part of a mesa type structure of the surface. The surface need not necessarily comprise a mesa. It is possible to provide a stress locally also in a flat semiconductor layer structure, such as a diode of the oxide strip

type, by means of one or several structured buffering layers which may comprise oxides as well as metals. Structuring of the covering layers is effected through structuring of the surface of the semiconductor body or in that the covering layers are provided with openings or are themselves provided locally. The influence of modifications in the geometry of the surface or of one or several covering layers or of the stresses built up therein on the position and value of the stress in the semiconductor layer structure can be estimated through calculations. An optimum or at least desired configuration may then be determined experimentally on the basis of these results.

It is also possible to replace the conductivity types all (simultaneously) with their opposites. Furthermore, a LED version or a laser version of a radiation-emitting semiconductor diode according to the invention may be chosen, depending on the application. It is finally noted that the methods of providing the semiconductor layers and conductive layers used in the embodiments - partly dependent on the material system in which the semiconductor diode is manufactured - may be replaced by techniques other than those mentioned here: thus LPE, VPE or MBE may be used instead of MOCVD and magnetron sputtering or vapor deposition may be used instead of diode sputtering for those layers which do not require a built-in stress.

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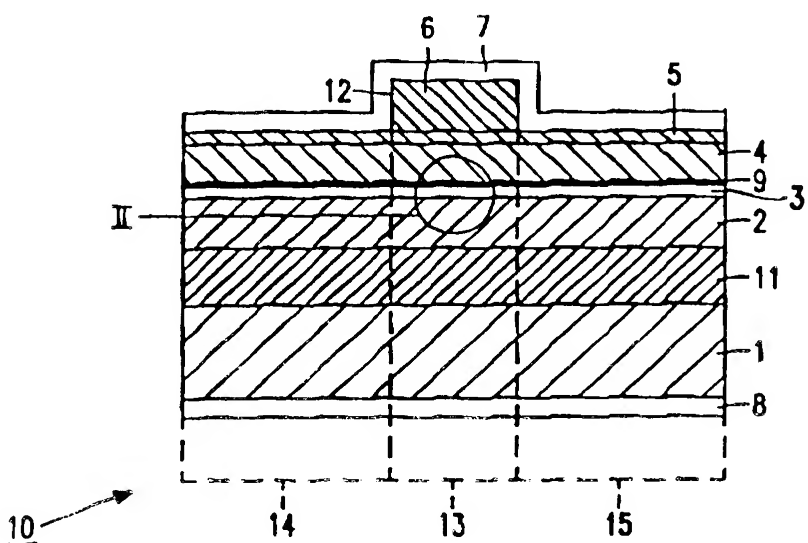
(54) Title: RADIATION-EMITTING SEMICONDUCTOR DIODE, AND METHOD OF MANUFACTURING SUCH A DIODE

(57) Abstract



A radiation-emitting semiconductor diode with a substrate (1) on which are situated: a first cladding layer (2), an active layer (3), and a second cladding layer (4), forms an important component in information-processing systems such as optical disc systems, especially when constructed as a laser. A laser in the GaInP/AlGaInP material system has a desired short-wave emission of, for example, 630 nm. According to the invention, such a diode comprises a barrier layer (9) which is present between the second cladding layer (4) and the active layer (3) and which prevents dopant elements, for example zinc atoms, from moving from the second cladding layer (4) to the active layer (3). The degradation which would otherwise occur was found to be connected with a local displacement of the pn junction from the second cladding layer owing to the stress in the layer structure which is necessary for the photoelastic effect. The barrier layer (9) preferably comprises two or more sub-layers (9A, 9B) with alternately a high and a low bandgap, in the GaInP/AlGaInP material system made of AlGaInP or AlInP with alternately a high and a low aluminum content. Such a barrier layer at the same time increases the efficiency of the diode according to the invention. In a major embodiment, the doping profile has a stepped gradient on either side of the active layer (3).

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Radiation-emitting semiconductor diode, and method of manufacturing such a diode.

The invention relates to a radiation-emitting semiconductor diode, in particular to a semiconductor diode laser often called laser hereinafter for short, comprising a semiconductor body with a semiconductor substrate on which are present at least in that order a first cladding layer of a first conductivity type, an active layer, and a second cladding layer of a second conductivity type opposed to the first, the first and second cladding layers being provided with means for the supply of an electric current and with a pn junction which, given a sufficiently high current strength in the forward direction, is capable of generating electromagnetic radiation in a strip-shaped active region of the active layer, while the surface of the semiconductor body is provided with at least one covering layer which is under mechanical stress and the surface of the semiconductor body or the covering layer is geometrically structured such that, and the mechanical stress of the covering layer is chosen such that the effective refractive index for the generated radiation is reduced in the active layer on either side of the strip-shaped active region. The invention also relates to a method of manufacturing such a diode and to a method of operating the laser version of such a diode.

Such a radiation-emitting diode, especially when constructed as a laser and when the wavelength of the emission lies in the visible range of the spectrum, forms a particularly suitable radiation source for inter alia information processing systems such as laser printers with which information is written, and such as optical disc systems in which information is read, for example so-called Compact Disc (CD) and Video Long Play (VLP) players, or is written and read, for example Digital Optical Recording (DOR). There are numerous applications in optoelectronic systems as well when such diodes are constructed as LEDs.

Such a radiation-emitting diode and such a method of manufacturing it are known from the article by R. Maciejko et al., "Photoelastic Effects on the emission patterns of InGaAsP ridge-waveguide lasers" published in IEEE Journal of Quantum Electronics, vol 25, no. 4, 4 April 1989, pp. 651-660. This describes a laser (see Fig. 2) in which an

InGaAsP active layer, a p-type InP second cladding layer, and an InGaAs(P) contact layer are present on an n-type InP substrate which also acts as the first cladding layer. The laser shown here is of the ridge waveguide type and of the index-guided type because the ridge comprises the entire second cladding layer. This means that the effective refractive index is lower on either side of the active region than in the active region. The surface of the laser is covered with a covering layer which has a mechanical stress, comprises an oxide, is provided with an opening above the ridge, and in its turn is covered with a metal layer. Fig. 7 of the article shows that an additional lowering of the effective refractive index occurs on either side of the active region in such a laser if the covering has a tension stress. Indeed, said tension stress in the covering layer introduces a compression stress on either side of the active region, and this in its turn leads to an additional lowering of the effective refractive index on either side of the active region as a result of a photoelastic effect. A narrow active region is promoted thereby, and as a result a more (circular-) symmetrical pattern of the emerging radiation beam. In addition, the starting current of the laser is comparatively low because of this, which is also very favorable.

It is a disadvantage of the known semiconductor diode when constructed as a laser that it shows a stronger degradation when used at a lower temperature, for example at 30 °C, than at a higher temperature, for example 50 to 80 °C. This is highly surprising because in general degradation tends to occur more readily at higher temperatures. Sometimes, however, the use at low temperature, for example in pulsed operation, is desirable, and in that case the degradation is inadmissibly high.

The present invention accordingly has for its object inter alia to realize a radiation-emitting semiconductor diode (and a simple method of manufacturing it) which do not involve the above disadvantage, or at least to a much lesser degree, the laser version of the diode showing a low degradation also at a low operating temperature.

According to the invention, a radiation-emitting semiconductor diode of the kind described in the opening paragraph is for this purpose characterized in that a barrier layer preventing the diffusion of dopant elements of the second conductivity type from the second cladding layer into the active layer is present between the active layer and the second cladding layer. The invention is based in the first instance on the surprising experimental result that the degradation which occurs especially in the use of a laser version of a diode at low temperature is connected with a displacement of the pn junction. This displacement is

found to occur mainly locally, i.e. approximately below the lateral sides of the ridge, and comprises a shift in the direction of and up to inside the first cladding layer. The invention is further based on the recognition that this local displacement is also partly caused by the stress in the structure present in situ. This stress promotes a local migration of atoms which give the second cladding layer the second conductivity type, for example zinc atoms, from the second cladding layer through the active layer to and into the first cladding layer. A pn junction which has been displaced (too far) results in degradation. The invention is finally based on the recognition that said displacement of the pn junction can be counteracted in that a barrier layer is provided between the second cladding layer and the active layer, i.e. a barrier obstructing the passage of dopant elements of the second conductivity type. The diode according to the invention, when constructed as a laser, has a particularly low degradation also at a low operating temperature: it is characterized by a total increase in the starting current of, for example, 5 %, whereas the known diode in that case shows an increase in the starting current of 100 %. It is noted that the expression "barrier layer between the active layer and the second cladding layer" is also understood to cover a barrier layer which is present within the active layer but in the portion thereof adjoining the second cladding layer as well as a barrier layer which is present within the second cladding layer at a small distance from the active layer, for example, separated therefrom by a so-called separate confinement layer. The barrier layer is thus effective at least for the major portion of the active layer or the major portion of the second cladding layer.

In a preferred embodiment of a radiation-emitting semiconductor diode according to the invention, the barrier layer comprises two or more sub-layers which have alternately a high and a low bandgap value. Such a barrier layer is found to be very effective in practice. A possible mechanism is that such a barrier layer prevents charge carriers, electrons in this case, from penetrating from the active layer into the cladding layer and giving off energy there which would promote a displacement of, for example, zinc atoms. If the barrier layer or the sub-layers is/are thin, for example thinner than 10 nm, they are allowed to have a mechanical stress without defects being caused thereby which would promote the degradation. Both a tension and a compression stress promote the effectivity of the barrier layer against, for example, zinc atoms: in the former case the lattice constant of the barrier layer is small(er), so that the zinc atoms, which are also small, are energetically stopped. In the latter case, the lattice constant of the barrier layer is great, so that it is indeed energetically favorable for the small zinc atoms to penetrate the barrier layer, but they are subsequently retained therein. The use of either kind of stress has the additional advantage

that the total net stress in the barrier layer can be very small as a result of compensation. The risk of defects arising is absent or at least very small as a result.

In a very favorable embodiment, the doping concentration at at least one side of the active layer, but preferably at both sides thereof, has a gradient, preferably stepwise, from a low to a high doping concentration. A low doping concentration (instead of, for example, a doping concentration equal to zero) has a stabilizing effect on the location of the pn junction. Such a concentration also reduces the diffusion length of the charge carriers, so that the latter can penetrate less far into the cladding layer and promote the diffusion of, for example, zinc there. A high doping concentration close to the active layer is undesirable because of its unfavorable influence on the luminescence, whereas a high doping concentration (farther away) in the cladding layer does not have this influence and is very favorable for the series resistance of the diode.

In a major embodiment, the surface of the semiconductor body is geometrically structured in that the semiconductor body is provided with a strip-shaped mesa which comprises at most a portion of the second cladding layer and which is present above the strip-shaped active region, while the covering layer comprises a metal layer which extends over the mesa and on either side thereof and is under a compression stress. The metal layer forms a current-blocking junction with the subjacent portion of the second cladding layer or with an intermediate layer, if present, on either side of the mesa. A covering layer comprising an oxide as known from the prior art diode may be absent in this embodiment, and no photolithographic process need be used for contacting of the diode. The manufacture of a diode according to the invention is very simple as a result of this.

In a particularly attractive modification of this embodiment, the strip-shaped mesa comprises exclusively a contact layer of the second conductivity type which is present on the second cladding layer, and the thickness and composition of the second cladding layer are chosen such that the generated radiation is fully confined at the side of the second cladding layer. Owing to this construction, the diode is in principle of the gain-guided type, which means that the current distribution determines the profile of the radiation beam. A purely gain-guided laser is often not of great practical use because a so-called anti-guiding effect may readily arise owing to various causes, whereby a filamentation of the radiation beam occurs. The compression stress in the covering layer, however, renders the present modification of the diode weakly index-guided, which ensures a symmetrical and non-filamented radiation beam. It is noted that surprisingly the covering layer must have a compression stress in these cases so as to obtain the desired (additional) reduction in the

effective refractive index on either side of the ridge, and not a tension stress as in the known structure.

Preferably, the diode according to the invention is constructed as a laser, the substrate comprises n-type GaAs, the respective n-type and p-type cladding layers comprise AlGaInP or AlInP, the active layer comprises GaInP or AlGaInP with a lower aluminum content than the cladding layers, the diode comprises a contact layer of p-type GaAs, the second cladding layer is doped with zinc atoms, the barrier layer comprises two or more layers of AlGaInP or AlInP with alternately a high and a low aluminum content, and the covering layer which is under mechanical stress comprises a tantalum layer.

A method of manufacturing a radiation-emitting diode whereby a semiconductor body is formed through the provision on a semiconductor substrate of, in that order: at least a first cladding layer of the first conductivity type, an active layer, and a second cladding layer of a second conductivity type, the surface of the semiconductor body being provided with a covering layer which is under mechanical stress, and the surface of the semiconductor layer or the covering layer being geometrically structured such that, and the mechanical stress of the covering layer being chosen such that the effective refractive index for the radiation to be generated is reduced in the active layer on either side of a strip-shaped active region forming part of the active layer, is characterized according to the invention in that a barrier layer is provided between the active layer and the second cladding layer, which barrier layer prevents dopant atoms of the second conductivity type from moving from the second cladding layer into the active layer. A diode according to the invention is obtained in a simple manner by such a method.

Preferably, in a method according to the invention, zinc is chosen as the dopant of the second conductivity type, the barrier layer is formed by two or more sub-layers with alternately a high and a low bandgap, the doping levels of the cladding layers on either side of the active layer are provided stepwise from low to high, and a layer comprising tantalum is chosen for the covering layer, the latter being provided by diode sputtering at a high power or at a low argon pressure.

The invention will now be explained in more detail with reference to an embodiment and the accompanying drawing, in which

Fig. 1 is a diagrammatic cross-section of an embodiment of a radiation emitting semiconductor diode according to the invention,

Fig. 2 is a diagrammatic cross-section taken on the line II in Fig. 1 of a detail of the diode of Fig. 1; and

Figs. 3 and 4 diagrammatically and in cross-section show the diode of Fig. 1 in consecutive stages of its manufacture by a method according to the invention.

The Figures are diagrammatic and not drawn true to scale, the dimensions in the thickness direction being particularly exaggerated for greater clarity. Corresponding parts have generally been given the same reference numerals in the various examples. Semiconductor regions of the same conductivity type have generally been hatched in the same direction.

The cross-section of Fig. 1 shows a radiation-emitting semiconductor diode according to the invention constructed as a laser. Fig. 2 shows a detail II of the laser of Fig. 1. The laser comprises a semiconductor body 10 with a substrate region 1 of a first conductivity type, here the n-type, provided with a connection conductor 8 and comprising monocrystalline gallium arsenide in this example. A semiconductor layer structure is provided on this, comprising inter alia a buffer layer 11 of the same, i.e. the n-conductivity type. Silicon atoms are used for the n-type doping in this example. On the above assembly the following are provided in that order: a first cladding layer 2 of the n-conductivity type, an active layer 3, a second cladding layer 4 of the opposed, i.e. p-conductivity type, and a contact layer 6 also of the p-type. Zinc atoms are used for the p-type doping here. The surface of the semiconductor body 10 is geometrically structured in that it is provided with a strip-shaped mesa 12 which here comprises exclusively the contact layer 6, the doping profile of which is provided in steps. A pn junction present between the cladding layers 2 and 4 is capable of generating electromagnetic radiation in a strip-shaped active region 13 present in the active layer 3 below the mesa 12, given a sufficient current strength in the forward direction. A covering layer 7 extends over the surface of the semiconductor body, has a mechanical stress, a compression stress in this case, and comprises a metal layer 7 in this example which at the same time serves as an electrical connection for the second cladding layer 4. This geometric structure of the surface of the semiconductor body 10 and the covering layer 7, and the compression stress present therein give rise to a tension stress in the active layer 3 (approximately) below the edges of the mesa 12, which results in a lower effective refractive index in said locations for the generated radiation. This embodiment of the laser is weakly index-guided instead of purely gain-guided as a result. This means that

the radiation beam is forced underneath the mesa 12 and does not easily become filamented, but is rather more circular-symmetrical. The starting current of such a laser is also considerably lower than if the laser were of the gain-guided type, because in the latter case a so-called anti-guiding will arise in practice which leads to filamentation of the radiation beam and to an increase in the starting current of the laser.

According to the invention (see especially Fig. 2), a barrier layer 9 is present in the diode, so here in the laser, between the active layer 3 and the second cladding layer 4, which constitutes a barrier to dopant elements of the second conductivity type, so zinc atoms in this case, preventing at least that these doping elements move beyond the barrier layer into the active layer 3. The invention is based on a number of surprising finds and recognitions that a diode constructed as a laser shows a strong degradation especially at a low temperature of use; that this degradation is accompanied by, and indeed caused by a displacement of the pn junction; that this displacement is mainly local, i.e. approximately below the lateral edges of the mesa 12 and comprises a shift in the direction of and into the first cladding layer 2; that this local displacement is caused by the stresses present in the structure in situ, which stresses apparently promote migration of atoms which give the second cladding layer the second conductivity type, zinc atoms in this case, from the second cladding layer 4 through the active layer 3 to and into the first cladding layer 2; and finally that said displacement is counteracted by the application of a barrier layer 9 between the second cladding layer 4 and the active layer 3, thus raising a barrier to zinc atoms in this case which at least limits, or even prevents the displacement of said atoms altogether. The laser in this example shows a particularly low degradation also at a low operating temperature, for example in the case of pulsed operation: it is characterized by a total increase in the starting current of, for example, 3 %, whereas a laser comparable to the known diode shows a degradation of 100 % in that case. A diode according to the invention also has a very favorable degradation of, for example, 5 % at a higher temperature of use.

An important advantage of a diode according to the invention is that the barrier layer 9 not only constitutes a barrier to doping elements but is also capable of contributing to the efficiency. As a result, the laser in the present example has a particularly low starting current of, for example, 20 mA and a particularly low temperature-dependence of the starting current. The starting current is 75 % higher in a laser whose covering layer 7 has no mechanical stress or the wrong mechanical stress, i.e. a tension stress in this case.

In this example of a laser manufactured in the GaInP/AlGaInP material system, the barrier layer 9 is formed by two or more, in this case 20 sub-layers 9A, 9B with

alternately a high (9A) and a low (9B) aluminum content and all approximately 1 nm thick. The barrier layer 9 is not intentionally doped here but will have the p-type conductivity owing to doping from the adjoining layers 4a, 4b. The barrier layer 9 in this example in addition increases the efficiency of the diode according to the invention. The barrier layer 9 may advantageously be given a mechanical stress, a compression as well as a tension stress will improve the operation of the barrier. A combination of the two kinds of stress has the additional advantage that the net stress in the barrier layer 9 can be low or even zero, so that the generation of defects and the accompanying degradation can be avoided. In the present example, the two cladding layers 2, 4 comprise so-called separate confinement layers 2b, 2c, 4b, 4c of small thickness. These are not shown in the drawing. The barrier layer 9 is accordingly situated here within the second cladding layer 4 at a small distance from the active layer 3, this distance corresponding to the sum of the thicknesses of the separate confinement layers 4b, 4c. The doping concentration of the two cladding layers 2, 4 has a stepped gradient in this example: the portions of the cladding layers 2, 4 adjoining the active layer 3 have no more than the background doping - seen from the active layer 3 - which is, for example, approximately 10^{16}, then a somewhat higher doping concentration of $1*10^{17}$ at/cm^3, and finally a highest doping concentration of $2*10^{18}$ at/cm^3. A shift of the pn junction is further counteracted thereby, while the diffusion length of the charge carriers is sufficiently but not excessively limited, and the diode still has a useful series resistance of, for example, 6 Ω.

The covering layer 7, which comprises a metal layer 7 here, forms a current-blocking junction with the subjacent portion of the semiconductor body 10, in this case with an intermediate layer 5, on either side (14, 15) of the mesa 12. The metal layer 7 comprises the following sub-layers: a first sub-layer of platinum which provides the electrical contact with the semiconductor body 10 and which is preferably between 20 and 100 nm thick, 50 nm in this example. Then a second sub-layer of tantalum which is preferably between 100 and 200 nm thick, 150 nm in this example. This second sub-layer comprising tantalum gives the metal layer 7 a compression stress in this example. Finally, the metal layer 7 comprises a third sub-layer of gold which is preferably between 50 and 200 nm thick, 50 nm thick in this case, and which enables, for example, soldering of the laser. The metal layer 7 is preferably provided by sputtering. During the necessary alloying process of the platinum portion of the metal layer 7 with the semiconductor body 10, the former is given a tension stress. If the metal layer 7 is to be given a compression stress, as is necessary in this example, the alloying process of the platinum must take place before the sub-layers

comprising tantalum and gold of the metal layer 7 are provided. The sub-layer comprising tantalum is then given a sufficiently high compression stress, so that the resulting metal layer 7 will have the compression stress desired here (also after an unstressed layer comprising gold has been provided). The sub-layer comprising tantalum may be given a compression stress in that it is provided by diode sputtering at a comparatively low argon pressure, for example below approximately 25 μbar, or in that it is sputtered at a high power (for example during diode sputtering), in which case the temperature of the semiconductor body 10 becomes comparatively high, for example much higher than 300 °C, while the layer comprising tantalum is being provided. It is noted that a so-called annealing step should be avoided as much as possible here because any built-in compression stress is reduced by such a step or may even be converted into a tension stress.

The radiation-emitting semiconductor diode is constructed as a diode laser in this example. This means that the emission is coherent given a sufficient current strength. The strip-shaped mesa 12 is bounded perpendicularly to the longitudinal direction by two mutually parallel mirror surfaces lying in the plane of drawing and coinciding with natural cleaving surfaces of the crystal from which the semiconductor body was formed for the purpose of the diode laser version. This results in a resonant cavity for the generated radiation within the strips-shaped region 13 in the active layer 3.

The compositions, intentional doping concentrations, and thicknesses used for the various semiconductor layers in this example have been listed (once more) in the Table below.

No.	Material	Type	Doping concentr. (at/cm^3)	Thickness (μm)	Bandgap (eV)
1	GaAs	N	$2x10^{18}$	100	1,4
11	$Al_{0.20}Ga_{0.80}As$	N	$2x10^{18}$	0,1	1,7
2a	$Al_{0.35}Ga_{0.15}In_{0.50}P$	N	$2x10^{18}$	0,8	2,3
2b	$Al_{0.20}Ga_{0.30}In_{0.50}P$	N	$1x10^{17}$	0,096	2,15
2c	$Al_{0.20}Ga_{0.30}In_{0.50}P$	-	-	0,004	2,15
3	$Ga_{0.38}In_{0.62}P$ (2x) $Al_{0.20}Ga_{0.30}In_{0.5}P$ (1x)	- -	- -	0,006 0,004	1,9 2,15
4c	$Al_{0.20}Ga_{0.30}In_{0.50}P$	-	-	0,004	2,15
4b	$Al_{0.20}Ga_{0.30}In_{0.50}P$	P	$1x10^{17}$	0,096	2,15
9A	$Al_{0.35}Ga_{0.15}In_{0.50}P$ (10x)	-	-	0,002	2,3
9B	$Al_{0.20}Ga_{0.30}In_{0.50}P$ (10x)	-	-	0,002	2,15
4a	$Al_{0.35}Ga_{0.15}In_{0.50}P$	P	$4x10^{17}$	0,8	2,3
5	$Ga_{0.50}In_{0.50}P$	P	$1x10^{18}$	0,08	1,9
6	GaAs	P	$2x10^{18}$	0,25	1,4
	GaAs	P	$2x10^{19}$	0,2	1,4

The radiation emitted by this semiconductor diode has a wavelength of approximately 675 nm. The width of the mesa-shaped strip 12 is approximately 6 μm. The conductive layer 8 on the substrate 1 in this example is a gold-germanium-nickel layer with a thickness of approximately 100 nm.

The radiation-emitting semiconductor diode described is manufactured as follows according to the invention (see Figs. 3 and 4). Manufacture starts with a substrate 1 of monocrystalline n-type gallium arsenide with a doping concentration of $2x10^{18}$ at/cm^3 and a thickness of, for example, 350 μm. After polishing and etching of the surface, which

preferably has a misorientation of at most 6 degrees relative to the (001) orientation, the following layers are grown on this surface, for example from the gas phase by means of OMVPE (- Organo Metallic Vapor Phase Epitaxy) in that order: the buffer layer 11, the first cladding layer 2, the active layer 3, the barrier layer 9 and the second cladding layer 4, the intermediate layer 5, and the contact layer 6. The materials, compositions, doping concentrations, and thicknesses for these layers are chosen as indicated in the Table above.

After the semiconductor layer structure thus obtained has been removed from the growing apparatus and has been cleaned in a usual manner, a strip-shaped mesa 12 is formed by etching through an SiO_2 mask 30 (see Fig. 4). The contact layer 6 is removed by means of an etchant comprising NH_3, H_2O_2, and H_2O in the ratio 2:1:50, the etching rate being approximately 0.7 μm/hour at room temperature. The intermediate layer 5 serves as an etching stopper layer. The mask 30 is subsequently removed, and the substrate 1 is grinded down to about 100 μm. Then the structure is introduced into a sputtering device upside down for providing the covering layer 7, i.e. a metal layer 7. First 50 nm Pt is provided. Then, in another sputtering process the metal layer 8 comprising AuGeNi is provided on the substrate 1. After removal from the sputtering device, the Pt is alloyed with the contact layer 6 of GaAs in an alloying oven at a temperature of 380 °C during 20 minutes in an argon atmosphere. After removal from the alloying oven and replacement in the sputtering device, the structure is given a 150 nm thick tantalum layer by means of diode sputtering at a power of 1000 watts and an argon pressure of 3×10^{-2} mbar. The tantalum layer is put under a compression stress of approximately 7 kbar thereby. Then a 50 nm thick gold layer is sputtered onto the tantalum layer, whereby the stress built up in the metal layer 7 is not changed anymore. After removal from the sputtering device, and after cleaving in two mutually perpendicular directions, the lasers obtained, having dimensions of, for example 300×300 μm^2, are ready for final mounting.

The invention is not limited to the embodiments given, since many modifications and variations are possible to those skilled in the art within the scope of the invention. Thus semiconductor materials or compositions of the chosen semiconductor materials other than those mentioned in the examples may be used, if so desired, such as those from the GaAs/AlGaAs or InP/InGaAsP material systems. Instead of weakly index-guided, the diode according to the invention may also be made strongly index guided, which means that a major portion of the second cladding layer forms part of a mesa-type structure of the surface. The surface need not necessarily comprise a mesa. It is possible to provide a stress locally also in a flat semiconductor layer structure, such as a diode of the oxide strip

type, by means of one or several structured buffering layers which may comprise oxides as well as metals. Structuring of the covering layers is effected through structuring of the surface of the semiconductor body or in that the covering layers are provided with openings or are themselves provided locally. The influence of modifications in the geometry of the surface or of one or several covering layers or of the stresses built up therein on the position and value of the stress in the semiconductor layer structure can be estimated through calculations. An optimum or at least desired configuration may then be determined experimentally on the basis of these results.

It is also possible to replace the conductivity types all (simultaneously) with their opposites. Furthermore, a LED version or a laser version of a radiation-emitting semiconductor diode according to the invention may be chosen, depending on the application. It is finally noted that the methods of providing the semiconductor layers and conductive layers used in the embodiments - partly dependent on the material system in which the semiconductor diode is manufactured - may be replaced by techniques other than those mentioned here: thus LPE, VPE or MBE may be used instead of MOCVD and magnetron sputtering or vapor deposition may be used instead of diode sputtering for those layers which do not require a built-in stress.

Claims:

1. A radiation-emitting semiconductor diode comprising a semiconductor body (10) with a semiconductor substrate (1) on which are present at least in that order a first cladding layer (2) of a first conductivity type, an active layer (3), and a second cladding layer (4) of a second conductivity type opposed to the first, the first and second cladding layers (2, 4) being provided with means (6, 7, 8) for the supply of an electric current and with a pn junction which, given a sufficiently high current strength in the forward direction, is capable of generating electromagnetic radiation in a strip-shaped active region (13) of the active layer (3), while the surface of the semiconductor body (10) is provided with at least one covering layer (7) which is under mechanical stress and the surface of the semiconductor body (10) or the covering layer (7) is geometrically structured such that, and the mechanical stress of the covering layer (7) is chosen such that the effective refractive index for the generated radiation is reduced in the active layer (3) on either side of the strip-shaped active region (13), characterized in that a barrier layer (9) preventing the diffusion of dopant elements of the second conductivity type from the second cladding layer (4) into the active layer (3) is present between the active layer (3) and the second cladding layer (4).

2. A radiation-emitting semiconductor diode as claimed in Claim 1, characterized in that the barrier layer (9) comprises two or more sub-layers (9A, 9B) which have alternately a high and a low bandgap value.

3. A radiation-emitting semiconductor diode as claimed in Claim 1 or 2, characterized in that the barrier layer (9) has a mechanical stress and preferably partly has a compression stress, partly a tension stress.

4. A radiation-emitting semiconductor diode as claimed in Claim 1, 2 or 3, characterized in that the doping concentration at at least one side of the active layer (3), but preferably on both sides thereof, has a gradient, preferably stepwise, from a low concentration to a high concentration.

5. A radiation-emitting semiconductor diode as claimed in Claim 1, 2, 3 or 4, characterized in that the surface of the semiconductor body (10) is geometrically structured in that the semiconductor body (10) is provided with a strip-shaped mesa (12) which comprises at most a portion of the second cladding layer (4) and which is present

above the strip-shaped active region (13), while the covering layer (9) comprises a metal layer (9) which extends over the mesa (12) and on either side (14, 15) thereof and is under a compression stress.

6. A radiation-emitting semiconductor diode as claimed in Claim 4, characterized in that the strip-shaped mesa (12) comprises exclusively a contact layer (6) of the second conductivity type which is present on the second cladding layer (4), and the thickness and composition of the second cladding layer (4) are such that the generated radiation is fully confined by the second cladding layer (4).

7. A radiation-emitting semiconductor diode as claimed in any one of the preceding Claims, characterized in that the semiconductor diode is constructed as a semiconductor diode laser, and in that the semiconductor substrate (1) comprises gallium arsenide (GaAs) and is of the n-conductivity type, the cladding layers (2, 4) comprise aluminum-gallium-indium phosphide (AlGaInP) or aluminum-indium phosphide (AlInP), the active layer (3) comprises gallium-indium phosphide (GaInP) or aluminum-gallium-indium phosphide (AlGaInP) with a lower aluminum content than the cladding layers (2, 4), a contact layer (6) comprises gallium arsenide (GaAs), the second cladding layer (4) is doped with zinc atoms, the barrier layer (9) comprises two or more layers (9A, 9B) of aluminum-gallium-indium phosphide (AlGaInP) or aluminum-indium phosphide (AlInP) with alternately a high and a low aluminum content, and the stressed covering layer (7) comprises a layer containing tantalum.

8. A method of manufacturing a radiation-emitting diode whereby a semiconductor body (10) is formed through the provision on a semiconductor substrate (1) of, in that order: at least a first cladding layer (2) of the first conductivity type, an active layer (3), and a second cladding layer (4) of a second conductivity type, the surface of the semiconductor body (10)being provided with a covering layer (7) which is under mechanical stress, and the surface of the semiconductor layer (10) or the covering layer (7) being geometrically structured such that, and the mechanical stress of the covering layer (7) being chosen such that the effective refractive index for the radiation to be generated is reduced in the active layer (3) on either side of a strip-shaped active region (13) forming part of the active layer (3), characterized in that a barrier layer (9) is provided between the active layer (3) and the second cladding layer (4), which barrier layer (9) prevents dopant atoms of the second conductivity type from diffusing from the second cladding layer (4) into the active layer (3).

9. A method as claimed in Claim 8, characterized in that a contact layer (6)

of the second conductivity type is provided on the second cladding layer (4), the surface of the semiconductor body (10) is geometrically structured through the provision of a strip-shaped mesa (12) which comprises the contact layer (6), and the covering layer (7) is provided over the strip-shaped mesa (12) and on either side (14, 15) thereof and is provided with a compression stress.

10. A method as claimed in Claim 8 or 9, characterized in that zinc is chosen as the dopant of the second conductivity type, the barrier layer (9) is formed by two or more sub-layers (9A, 9B) with alternately a high and a low bandgap value, the cladding layers (2, 4) on either side of the active layer (3) are first weakly doped and farther removed from the active layer (3) strongly doped, and a layer (7) comprising tantalum is chosen for the covering layer (7) and is provided by diode sputtering at a high power or at a low argon pressure.

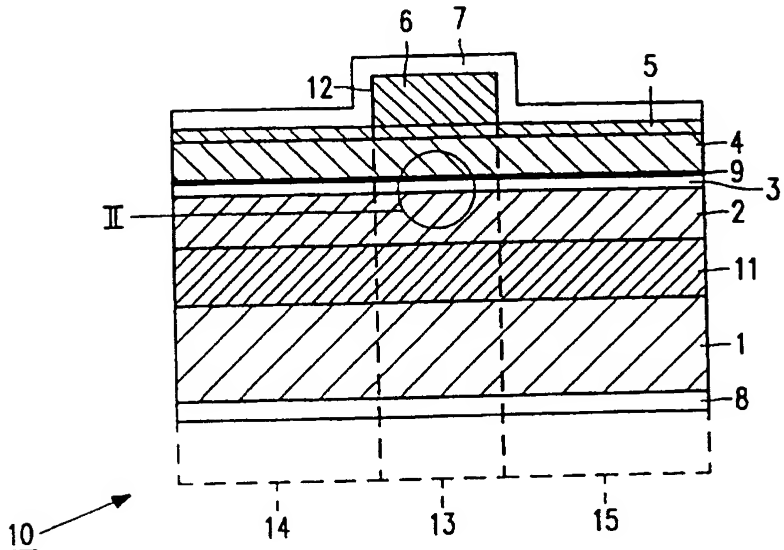

FIG. 1

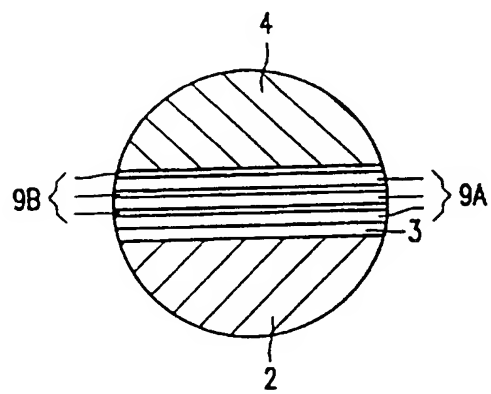

FIG. 2

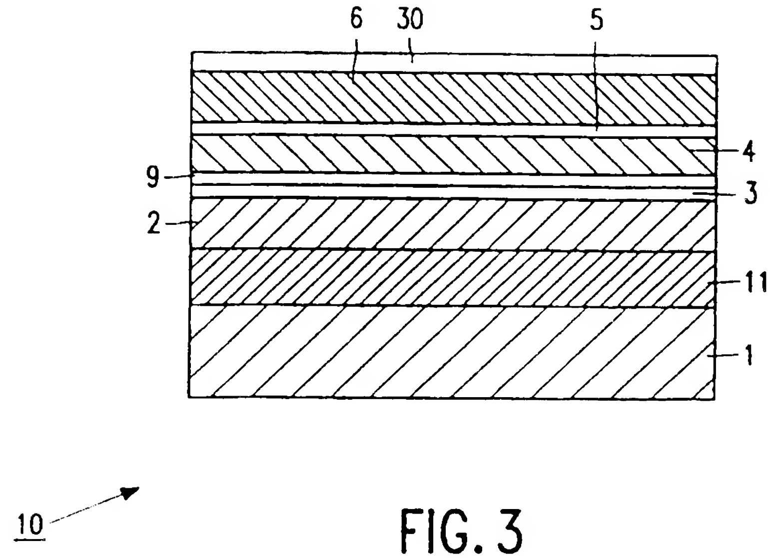

FIG. 3

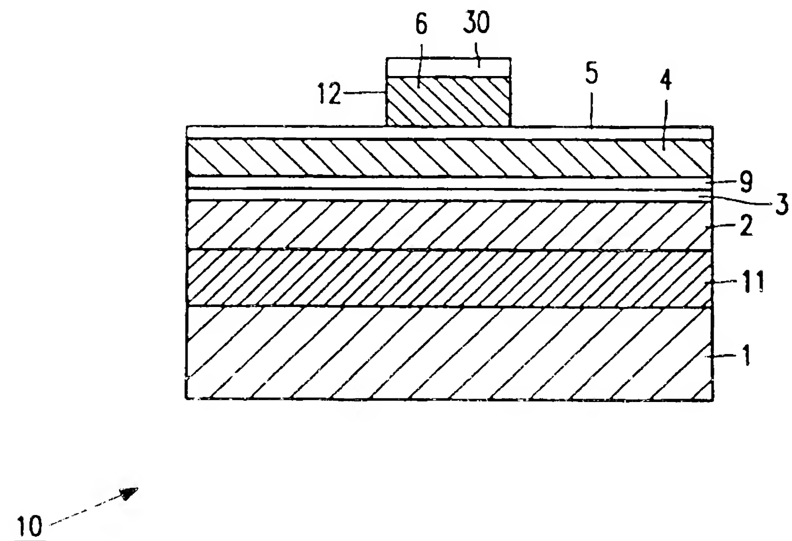

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 97/00612

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H01L 33/00, H01L 29/15, H01L 21/329 // H01S 3/19
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H01S, H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DIALOG: 2,350,351,434

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,A	WO 9700546 A2 (PHILIPS ELECTRONICS N.V. ET AL), 3 January 1997 (03.01.97), figures 1-3, claims 1-3, 8, abstract --	1-10
A	EP 0557638 A2 (MITSUBISHI DENKI KABUSHIKI KAISHA), 1 Sept 1993 (01.09.93), figure 1, claims 1-10, abstract --	1-10
A	EP 0540799 A1 (INTERNATIONAL BUSINESS MACHINES CORPORATION), 12 May 1993 (12.05.93), figures 3A, 3B,7-9, claims 1-14, abstract --	1-10

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 December 1997	04 -12- 1997
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Pär Moritz Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 97/00612

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	EP 0518320 A2 (SUMITOMO ELECTRIC INDUSTRIES LIMITED), 16 December 1992 (16.12.92), column 2, line 27 - column 3, line 56, figures 1-7, claims 1-11 --	1-10
A	EP 0390262 A1 (N.V. PHILIPS' GLOEILAMPENFABRIEKEN), 3 October 1990 (03.10.90), see the whole document. -- --------	1-10

INTERNATIONAL SEARCH REPORT
Information on patent family members

01/10/97

International application No.
PCT/IB 97/00612

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